United States Naval Facilities Engineering Command
United States Air Force Civil Engineering Support Agency

NAVFAC MO-102.10
AFJH 32-1001

Concrete Crack and Partial Depth Spall Repair Field Manual

Table of Contents

Author

Dr. J. Kent Newman, U.S. Army Engineer Waterways Experiment Station (WES), Vicksburg, MS.

Preface

This manual contains information on current practices (as of September 1995) for the repair of cracks and spalls in concrete as well as on the selection of materials and equipment. This manual is intended for use as a field manual for airfield concrete repair for all U.S. Navy, and Air Force facilities; however, the techniques for repair can be used for other concrete pavements as well. References are provided for additional information on pavement repair practices not addressed in this manual.

Safety Considerations

It is the responsibility of supervisory personnel to ensure worker safety by informing the workers of any potential hazardous practices. Occupational Safety and Health Administration (OSHA) guidelines must be followed at all times for hazardous practices such as sandblasting joints and cracks, airblasting for cleaning cracks, and working with chemicals. Workers are required to be informed of all hazardous materials and practices that may involve exposure to toxic materials in the workplace. Material Safety Data Sheets must be available to all workers at the work site.

Acknowledgments

Funding for the preparation of this manual was provided by the Naval Facilities Engineering Command (NAVFAC), Norfolk, VA. Monitors at NAVFAC were Mr. Charlie Schiavino and Mr. Vincent Donnally. Funding for printing of the manual was provided by the Air Force Civil Engineering and Services Center, Tyndall AFB, FL, and NAVFAC. Graphics illustrations were constructed by August Giffin, Applied Research Associates, Inc.

Note: Personnel responsible for repairs to airfield facilities are generally referred to as “base engineers” on Army and Air Force installations. For Navy and some Army facilities, the term used may be “Public Works Department Engineer.” In this manual, the term “base engineer” refers to personnel responsible for maintenance and repair of airfield facilities.

Summary of Crack Repair

1. Select the proper sealant material for the area being repaired (see “Crack Sealants”); however, the sealant selected must conform to appropriate specifications and be authorized by base engineers before use. The repair should be timed such that sawed out cracks are not exposed for more than a few hours before sealing. If the cracks get wet, the repair operation must stop until the cracks are completely dry or the cracks dried with a heat lance (see Photo 5).

2. Saw or rout (Photos 3 and 4) the crack to the proper width and depth to reach the desired shape factor and recess (see “Shape Factors”) recommended by the manufacturer of the sealant to be used. For silicone sealants, use of a backer rod in lieu of separating tape is recommended (see “Crack Sealants”). Small cracks may be hand sawn (Photo 9).

3. Clean the crack faces by sandblasting using the multiple pass technique (Photo 11). While standing to one side of the crack, pass the wand along the crack face at an angle to allow a strong blast on one crack face; then step to the other side of the crack and reverse direction.

4. Blow debris out of the crack using compressed air; then clean the crack with high-pressure water (Photo 6). Make sure there is no loose material in the bottom of the crack.

5. Clean the area around the crack with a broom or vacuum sweeper to prevent debris from reentering the crack before sealing (Photo 7) .

6. Remember that the cleanliness of both crack faces is extremely important! Dirty crack faces are a major cause of loss of adhesion of the sealant to the crack face and subsequent failure of the crack repair. Place the sealant within 24 hr after sandblasting. If sealant is not placed within 24 hr, sandblast the face again, clean out the crack with high-pressure water and air, sweep and vacuum the surface around the crack, and then seal. If a finger wiped along the joint face picks up any dirt or dust, the joint or crack face is dirty and must be cleaned.

7. Place the backer rod immediately prior to sealing the crack (Photo 8). The backer rod must be at least 25 percent larger in diameter than the width of the crack and must be placed at the proper depth for the shape factor of the sealant being used (Photo 2). Seal the crack from the bottom up and from beginning to end in one stroke without interruption when practical (Photo 12).

8. After the crack repair operation is complete, clean the surrounding pavement and sweep away all potential materials that may cause FOD (Foreign Object Damage). Clean, lubricate, and properly store all equipment until the next repair operation.

Summary of Spall Repair

1. Refer to Figures 1-6 for details on repair spalls in various slab locations and spall repair boundaries. Select the spall repair materials and the spall repair procedure (saw and patch is recommended). The recommended patch materials are discussed in “Spall Repair Materials”; however, use of these materials (concrete, joint sealer, joint filler, etc.) must meet specifications and/or be authorized by base engineers. As with any repair operation, the cleanliness of the area to be patched is one of the most important factors in a long-lasting patch. Extra care must always be taken to ensure the repair area is clean before repair. The timing of the repair should be such that the prepared spall recess is not exposed to the elements for more than a few hours without additional cleaning.

2. Remove any sealant present in the joint or crack adjacent to the spall.

3. Cut a boundary around the area to a depth of at least 2 in. (5 cm) using a concrete or a hand saw (Photo 13). The spall repair area should be a minimum size of 1 square foot, with a minimum length and width of 12 in. (30 cm).

4. Remove the concrete inside the boundary to a depth of at least 2 in. (5 cm) using either a light jackhammer (less than 30 lb (14 kg)) equipped with a chipping hammer, scarifier, or high- pressure water blaster (Photo 14). If a dowel is exposed during the concrete removal, it must be replaced (see References 1, 6, or 9 for details on dowel replacement).

5. Check the underlying concrete for soundness and remove any concrete found to be unsound.

6. Clean out the spall recess using high-pressure water and compressed air.

7. Sweep the area to prevent debris from reentering the spall repair area.

8. Install preformed joint filler to provide a rigid boundary next to the joint or crack and to retain the shape of the joint. This filler must extend the full length of the joint or crack and for the full depth of the spall repair area.

9. If required for the repair material, apply bonding agent to the spall repair surface (Photo 16). Always ensure that the spall repair recess is clean before adding bonding agent or any repair material. If the spall repair area is large and portland cement concrete (PCC) is the repair material to be used, be sure to place the grout rapidly so areas do not begin to dry prior to filling the area. Place the spall repair material (Photo 17), finish the surface (Photo 18), and follow the curing procedure recommended by the manufacturer of the repair material or refer to the guidelines outlined in “Spall Repair Procedures.” Use of curing compounds that form a “skin” over the surface of the concrete to prevent water loss is recommended.

10. After curing is complete, saw the joint or crack to match the existing width and to provide fresh surfaces for sealing. Sandblast each face of the fresh sawcut, wash with high-pressure water, airblast, and sweep the area. Place the proper width backer rod at the required depth for the sealant. Place the sealant from the bottom up and in one smooth operation from the beginning to the end of the joint or crack.

11. After the spall repair operation is complete, clean and sweep the surrounding pavement of all potential materials that may cause FOD. In addition, clean, lubricate, and properly store all equipment until needed.

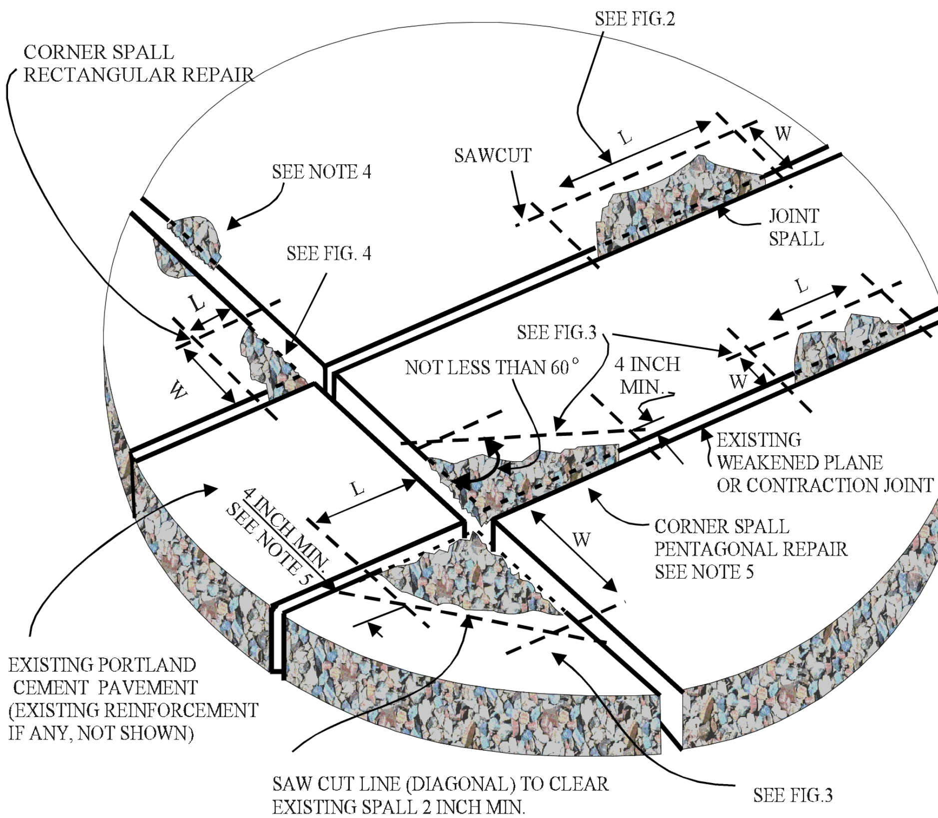

Figure 1. Plan of spall repairs (notes for figures begin on page 12; notes 1-5 apply to this figure)

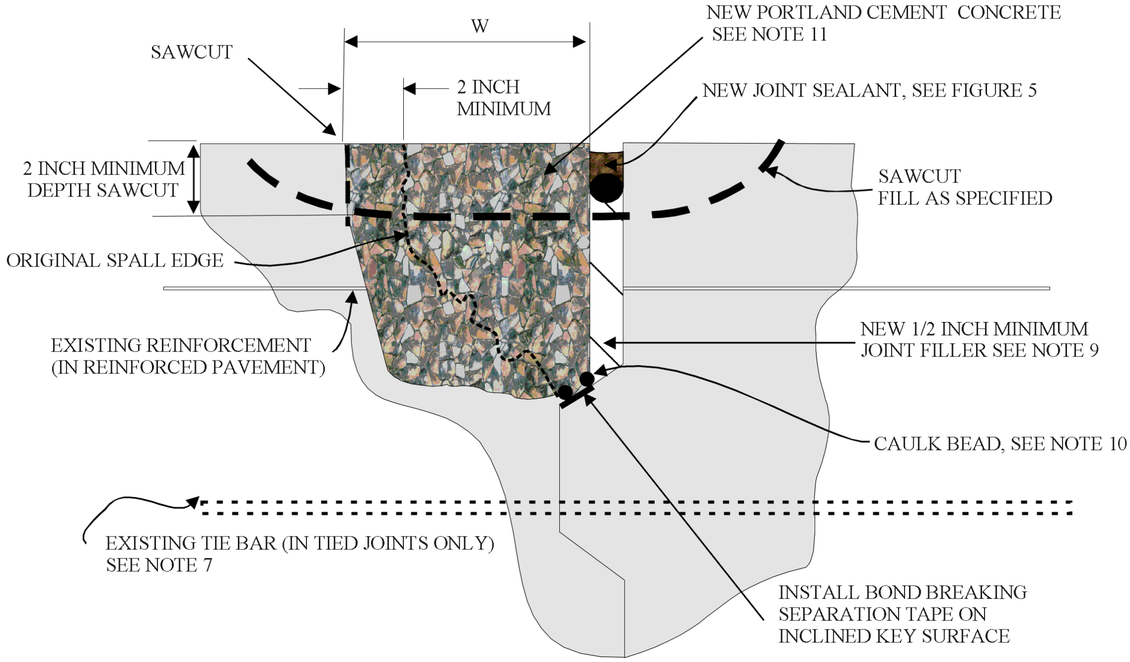

Figure 2. Spall repair at keyed construction joint

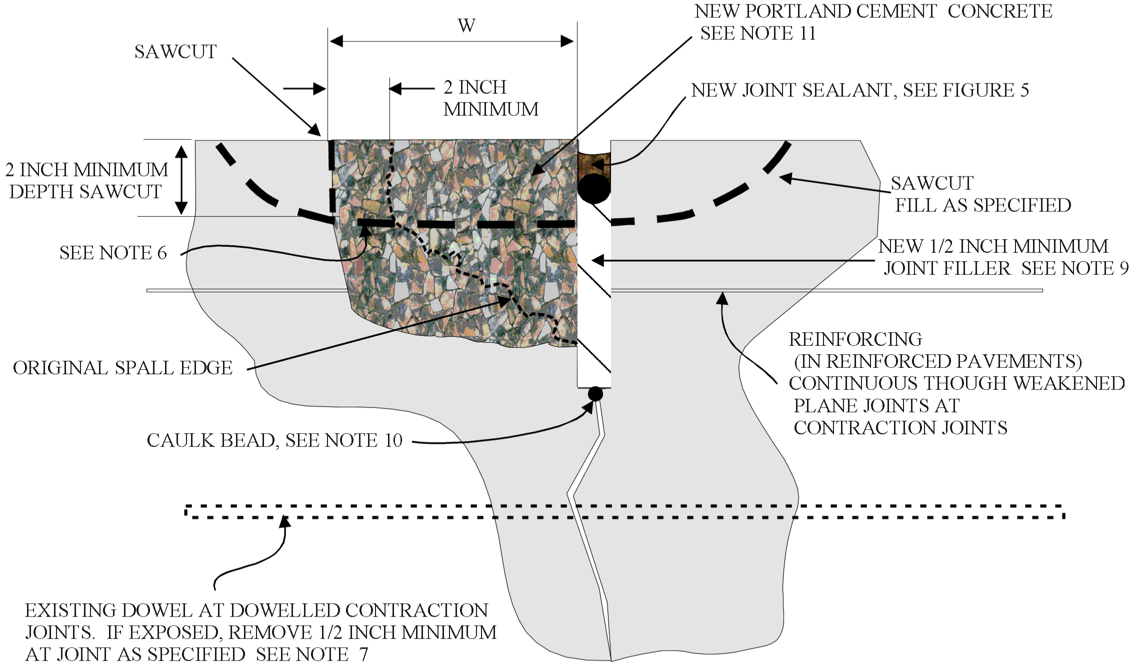

Figure 3. Spall repair at weakened plane or contraction joint

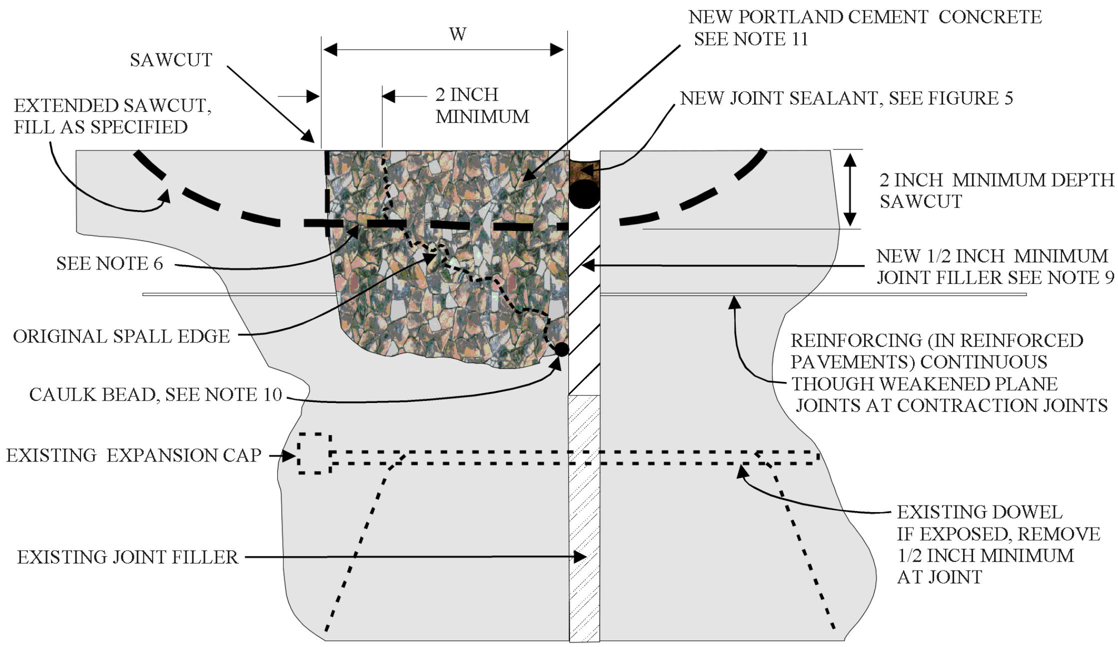

Figure 4. Spall repair at expansion joint

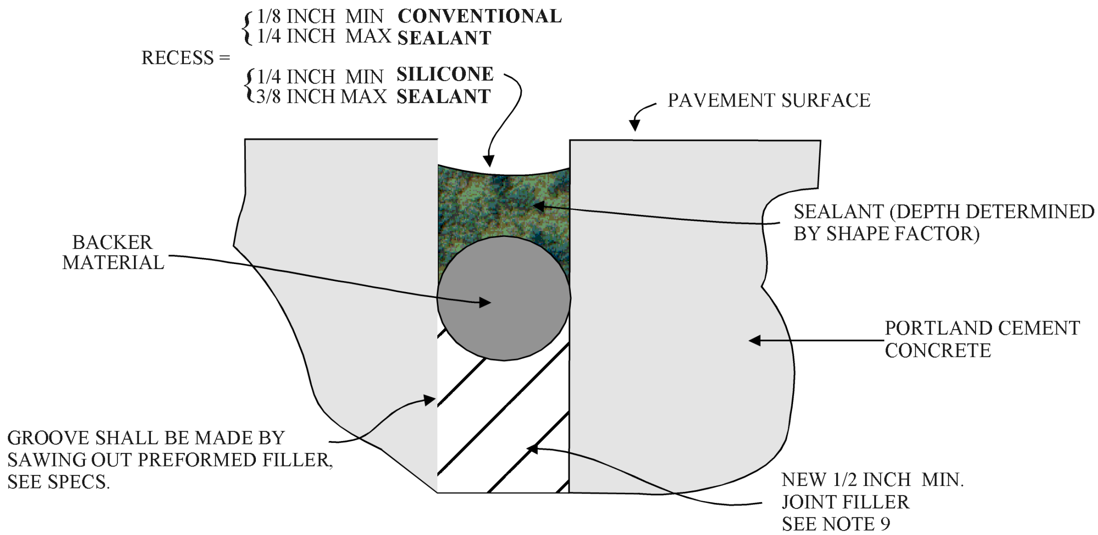

Figure 5. Groove for joint sealant at expansion point

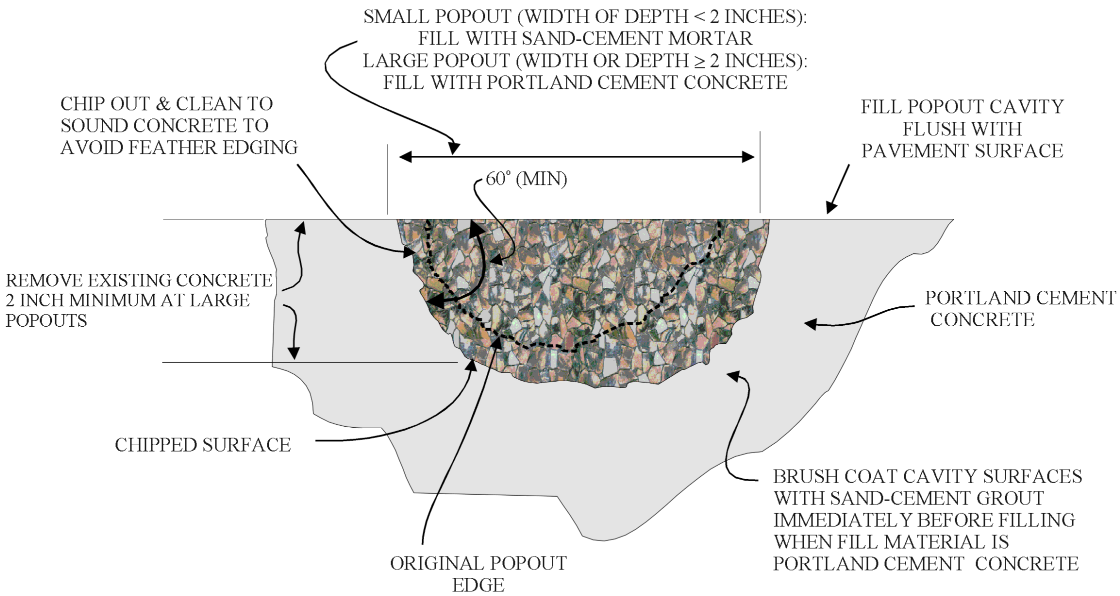

Figure 6. Typical section: popout repair

Note 1. Figures 1-6 are not drawn to scale. The minimum sides (both length (L) and width (W)) of a spall repair shall not be less than 12 in. (25 cm), regardless of the spall size. The locations of the intended sawcuts should be clearly marked.

Note 2. Spalls occur in many sizes and shapes. Repair details shown are intended for removal and replacement of all deteriorated concrete and to maintain the size of the spall repair to the minimum practical to ensure a lasting repair while avoiding unnecessary removal of sound concrete.

Note 3. Joint spalls with actual cavity widths less than 2 in. (5 cm) shall be repaired by cleaning and filling with joint sealant in lieu of PCC.

Note 4. Where spall repairs are required on each side of a joint or crack, a nonflexible type filler or insert shall be secured in alignment with the joint or crack after breaking out the spalled concrete. The spall repairs shall be completed on one side at a time. Under no circumstances should a spall repair bridge a joint or crack.

Note 5. At triangular corner spalls, the repair shall be made pentagonal to avoid feather-edged corners and to minimize the size of the repair area. The two sides of the repair area next to the joints should be a minimum of 12 in. (30 cm) in both length and width. Sawcuts shall be made at least 2 in. (5 cm) from each side of the spall and extending a minimum of 4 in. (10 cm) perpendicular to the joint. An additional sawcut is then made to intersect the two previous cuts at an approximately 60-deg angle with a minimum distance of 14 in. (30 cm). For corner spalls that are more rectangular in shape, a rectangular repair similar to that of a joint spall is conducted.

Note 6. Pavement and unsound concrete within sawcuts shall be broken out and removed to a depth not less than 2 in. (5 cm). Exposed cavity surfaces shall be cleaned as specified.

Note 7. Dowels, tie-bars, or continuous reinforcement exposed during preparation of the spall area shall be removed as specified for the width of the joint but not less than 1/2 in. (12 mm). See References 1, 6, and 9.

Note 8. A 1/2-in. (12-mm) width groove may be sawed at existing joint lines to a point 1/2 in. (12mm) below the prepared cavity surface to hold new fillers in place during concrete placement.

Note 9. Joint filler is required to maintain existing joints and working cracks. Width of the filler shall be equal to the width of the existing gap at the joint or crack and should extend at least 1 in. (2.5 cm) on each side of the prepared cavity. Depth of filler shall be not less than the depth of new patch materials. Joint filler should be neatly installed to prevent new grout or concrete from by-passing filler and entering the joint space.

Note 10. A neat bead of caulk may be applied as indicated to prevent grout or concrete from by-passing filler and entering the joint space. For keyed joints, an additional bead of caulk may be necessary to prevent grout or concrete from entering keyed joint.

Note 11. Repair personnel should apply and scrub sand-cement grout bonding course on all exposed cavity surfaces except faces of joints and working cracks. The cavity should be filled with concrete flush with the pavement surface. Sand-cement bonding grout is not to be used when a particular type of bonding agent is specified for a manufacturer’s material (for example, an epoxy bonding agent for an epoxy concrete).

Purpose of Crack and Spall Repair

The primary purpose of sealing cracks and repairing spalls in portland cement concrete on airfields is to reduce the costs associated with aircraft damage due to FOD (Foreign Object Damage) and to prolong the service life of the pavement for reducing the life-cycle costs for the pavement structure. A considerable investment has been made in the construction of a concrete surface and the vehicles that use these surfaces; therefore, costs decrease dramatically for every additional year of pavement use that does not cause vehicle damage or require repeated patching or full slab replacement. Routine periodic inspections and rapid repair of pavement problems are essential for reducing life-cycle costs (References 1 and 2). A properly constructed and maintained pavement can last for many years.

Spalling is generally caused by incompressible materials present in the joints and cracks that prevent the necessary movement of the slab due to thermal fluctuations, thereby causing breaks in the concrete adjacent to the joint or crack. Incompressible materials must be removed from the joint or crack, the spalled area patched, and the joint sealant replaced. Additional repairs of previous spall repairs due to failure of the material or poor repair practices are also common. If the spall depth is greater than the depth of half the slab, full-depth patching is needed. Full-depth patching will not be covered in this manual but is addressed in Reference 1. Cracking of slabs can be due to load-related failure or environmental stress on the slab.

The objective of crack sealing and spall repair is to reduce FOD and prevent moisture or incompressible material (rocks, sand, other pieces of concrete, etc.) from entering into the crack or joint. Unsealed cracks will allow moisture to penetrate under the slab causing an increase in the moisture content in the base and sub-base. As thermal cycling occurs and the joint or crack expands and contracts, incompressible material such as rocks, chunks of concrete, sand, or ice in the crack may cause stress to build in the slab, resulting in more spalling or cracking and further damage to the slab and increasing the potential for FOD.

When Do Cracks and Spalls Need Repair?

For airfields, inspections of the pavement surfaces receiving traffic should be conducted at least monthly to locate spalls or cracks that may cause FOD. Otherwise, routine field evaluations must be conducted at least biannually, once during the summer and once during the winter. Seasonal checks allow for evaluation of the material during the two extremes of stress on the pavement. Cracks and spalls should be located and inspected. If concrete has begun to break away from the crack or spalled area, the damaged area must be repaired. Cracks less than 1/4 in. (6 mm) wide with no spalling do not require sealing. Cracks larger than 1/4 in. (6 mm) and less than 2 in. (50 mm) must be sealed. Cracks larger than 2 in. (50 mm) require full-depth patching. Use of a backer rod is recommended for all crack repair. If spalling is present adjacent to a crack (no matter what the crack size), the damaged area must be repaired by treating the crack the same as an expansion joint. The sealed crack then prevents movement of the slab along the crack faces from destroying the spall repair.

An example of moderate severity spalling is shown in Photo 1. Spalls are present from the corner of the slab and along the face of the expansion joint. Missing chunks of concrete are visible with the potential for more pieces to become dislodged and cause FOD. All spalled areas with loose concrete (no matter how small) should be repaired to reduce FOD potential.

Photo 1. Moderate severity spalling along an expansion joint

Crack Repair

The recommended method for crack preparation is sawing the crack to the proper depth and width for the particular sealant and using backer rods. Each face of the sawcut must be sandblasted. The crack faces are then cleaned with high-pressure water and air, and the area swept with a vacuum broom to prevent the material from reentering the sawed crack. Small sections of repair are made at a time to prevent the sawed crack faces from being exposed to the elements for more than 24 hr. If the cracks are wet, they must be dried with a hot air lance or high-pressure air before placing the sealant and backer rod. The sealant used must conform to the applicable Federal specifications and must be approved for use at a particular facility by the base engineer. The sealant is placed in the crack from the bottom up and in one smooth run from the beginning to the end of the crack. The crack must be filled to a depth of 1/8 to 1/4 in. (3 to 6mm) for conventional sealant (Reference 3) and 1/4 to 3/8 in. (6 to 9 mm) for silicone sealant below the surface of the pavement (Reference 4).

A test section of approximately 200 linear ft (61 m) of cracks must be sealed before beginning the full crack sealing project. The same procedures and materials to be used in the full project must be used in the test section. Crack sawing or routing should be shown not to cause spalling. The crack faces must be clean before placement of any sealant. For two-component sealants, the correct mixing ratio must be verified to be within a specified tolerance according to the manufacturer’s specifications for that particular sealant. If using hot-applied sealants, calibrated thermometers must be used to verify correct application temperatures. All equipment must be shown to be in good working condition and operating properly. Additional details on joint and crack repair are given in References 5-9.

Crack Sealants

Crack repair sealants are essentially the same as joint sealants and are designed to mitigate two problem areas: moisture intrusion into the pavement base and debris retention in the crack opening. The influx of moisture through a crack into the pavement base layer can seriously reduce the strength of the base and the ability to sustain a load. Debris retention is a particular problem due to thermal movement of the slab at the joint. If incompressible material is present in the expansion joint and the slab expands due to thermal changes, spalling may result due to the inability of the stress to be relieved through movement of the slab at the crack.

Additional considerations for the crack repair material are jet fuel and jet blast resistance. The crack to be repaired may be located in an area in which fuel or lubricating or hydraulic fluid spillage may occur or in an area subjected to high temperature from jet blast or exhaust from auxiliary power units. The repair material must conform to Federal specifications designated for joint and crack sealants for use in these areas. The appropriate American Society for Testing and Materials (ASTM) testing procedures associated with these specifications are listed in the references section under "Joint and Crack Repair." Applicable Federal specifications (Reference 10) include:

SS-S-1401 Hot-applied sealant. Asphalt-based material containing virgin ground rubber, plasticizers, and reinforcing fillers. This material is a solid at room temperature. This material is not to be used in areas where fuel, lubrication fluids, or hydraulic fluids may be spilled.

SS-S-1614 Hot-applied jet-fuel-resistant sealant. Coal-tar-based material containing polyvinylchloride, plasticizers, and filler. This material may be either a solid or liquid at room temperature. This is not a jet-blast-resistant material.

SS-S-200 Cold-applied, two-component, jet-fuel- and jet-blast-resistant sealant. These materials typically contain coal tar and a polysulfide or polyurethane with fillers.

Naval regulations require that all materials used on U.S. Navy facilities must conform to NFGS-02982 (Reference 3). The Navy recommends use of silicone sealants on all naval facilities and as an alternative to materials meeting SS-S-200 if approved by the local base engineer. Silicone sealants may be used in place of neoprene sealants for new joints if cost becomes a major factor in placement of neoprene sealant (References 3 and 4). Sealants used on U.S. Army and Air Force pavements must conform to the Federal specifications listed above (References 3-5). Neoprene sealants are common on Air Force pavements.

Backer and Separating Materials

Backer material is placed in the sawed crack to minimize excess stress on the sealant material from improper shape factors and to prevent three-sided adhesion that would inhibit the ability of the sealant to expand and compress under thermal stress. Typically, backer materials are rod-shaped and are often referred to as “backer rod” (Photo 2). The backer material must be chemically inert to prevent reaction with the sealant, flexible to conform to the shape of the crack path, nonabsorptive to prevent water retention, nonshrinkable, and compressible to allow for easy installation. Typical backer materials are polychloroprene, polystyrene, polyurethane, and polyethylene closed-cell foams. Paper, rope, or cord should not be used. The melting temperature of the backer material must be at least 25 higher than the sealant application temperature to prevent damage during sealant placement. The uncompressed backer rod must have a diameter at least 25 percent larger than the sealant reservoir to ensure that it remains in

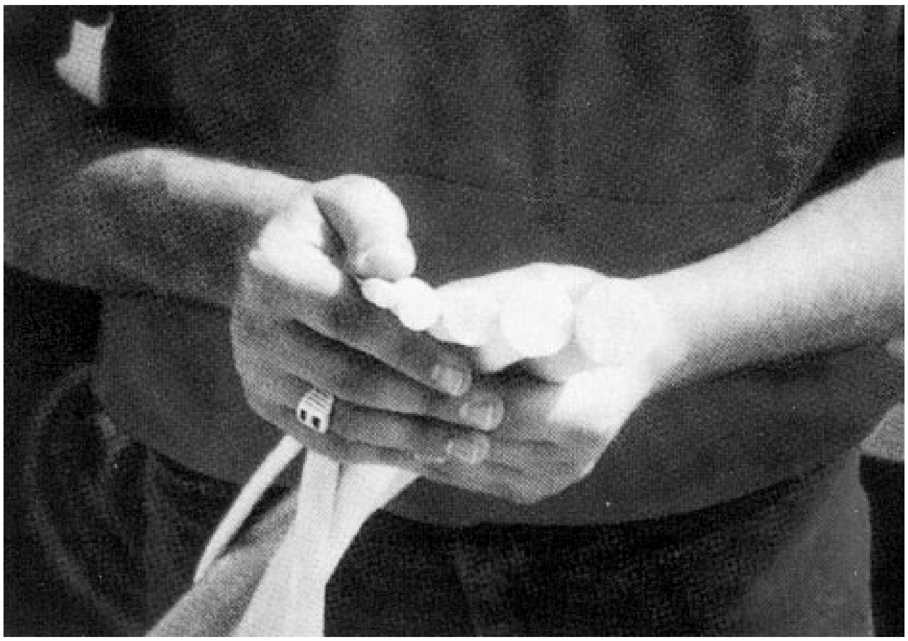

Photo 2. Examples of various sizes of backer rod

position during the sealing operation. Backer rod is the recommended material for repairing cracks.

Separating tape may be employed when the sealant reservoir dimensions correspond to that for the proper shape factor and the use of backer material would lead to an incorrect shape factor for that sealant material. Separating materials are usually a thin adhesive tape or a flexible plastic strip employed to prevent three-sided adhesion of the sealant. These materials must be flexible enough to deform with the sealant as the concrete expands and contracts. However, this repair method should only be used when the crack depth is shallow and cannot be deepened. Separating tape must not be used without prior authorization.

Shape Factors

For proper crack sealing, the crack must be routed or sawed (Photos 3, 4, and 9) to a designated width and depth for the particular type of sealant employed in the crack repair. The dimensions of a typical crack reservoir (see Figure 7) are defined by a shape factor (S = D/W) that is the ratio of the depth of the sealant (D) to its width (W). Shape factors generally range from 1.0 to 1.5; however, these dimensions may be particular for the type of sealant employed in the repair operation and a recommended value will be supplied by the sealant manufacturer. Silicone sealants require a shape factor of approximately 0.5 (Reference 3). For example, if the width (W) of the sawed crack is 1/2 in. (13 mm), the depth of the sawed crack (T) must be 1-1/8 in. (29 mm) to accommodate a backer rod of 5/8 in. (16 mm). The top of the backer rod will be at 1/2 in. (13mm) below the pavement surface. This allows for a depth (D) of 1/4 to 3/8 in. (6 to 9 mm) of silicone sealant on top of the crown of the backer rod to keep the sealant at 1/8 to 1/4 in. (3 to 6mm) below the pavement surface.

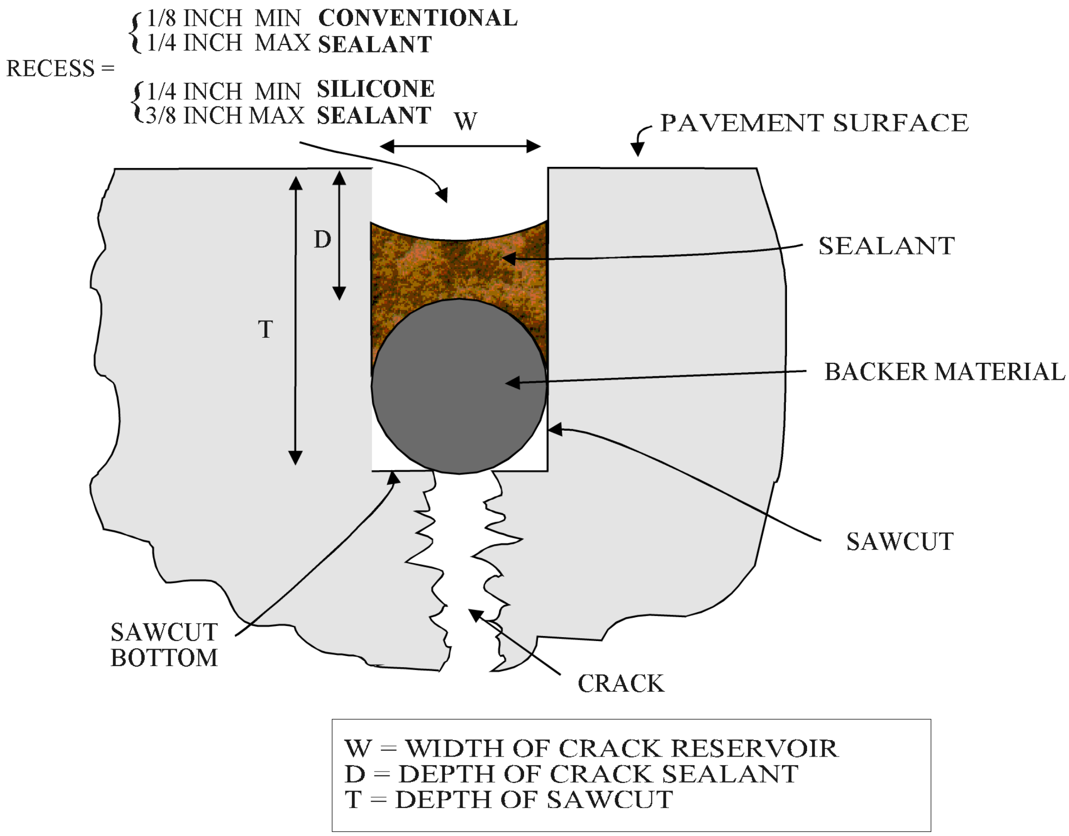

Figure 7. Diagram of a properly repaired crack showing dimensions of a typical sealant reservior

Crack Repair Equipment

All equipment employed in the crack repair operation must be inspected before, during, and after the repair project to ensure proper operation of the equipment, safety of the personnel involved in the project, and potential damage to the pavement due to equipment problems. Proper safety procedures in accordance with OSHA guidelines and common sense practices must be followed for the protection of all project personnel. Hand tools should always be available for working in areas where machinery is not practical or allowed.

All sealant equipment must be equipped with nozzles designed to fill the cracks from the bottom up. The equipment must be inspected daily prior to application of the sealant and during the operation to ensure safe operation and that the sealant is being applied properly.

Random crack saw

Sawing is the preferred method for preparing cracks for sealing. This device is essentially a concrete saw but has a smaller rear-mounted blade approximately 5 in. (13 cm) in diameter (Photo 3). These saws are generally self-propelled machines with caster wheels that allow more freedom of movement than a concrete saw for following the path of cracks. Diamond blades are typically employed and should be thick enough to saw the crack to the desired width and prevent warping of the blade during operation.

Vertical Spindle Router

Cracks may be routed out if a saw is not available. The vertical spindle router has a vertically mounted router bit and is constructed such that the device can easily follow the contours of a crack (Photo 4). The bit must be the proper size for the sealant reservoir and be belt-driven for safety considerations arising from jamming of the bit if the router is forced along the crack. The bits must yield the proper shape for the sealant reservoir and not cause spalling along the crack path.

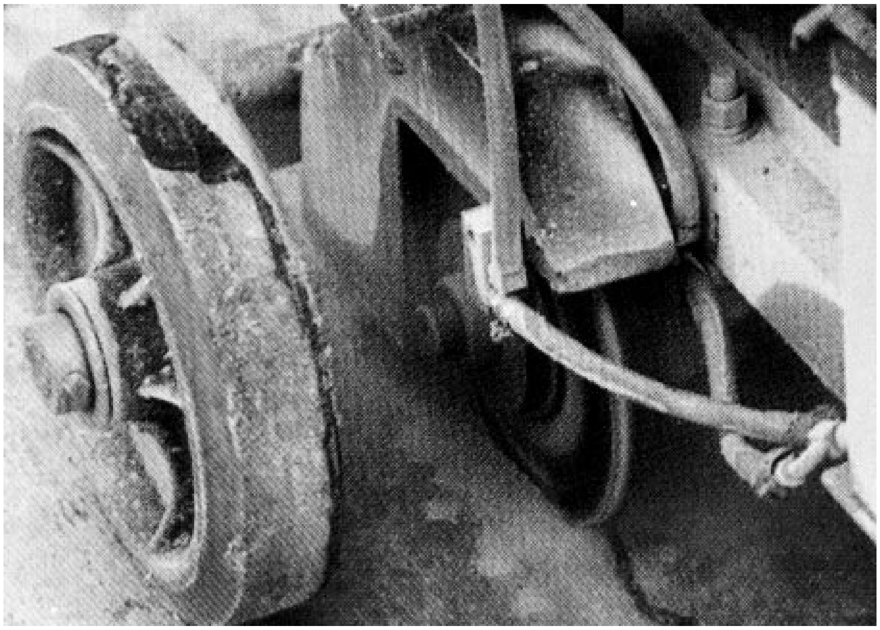

Photo 3. Random crack saw

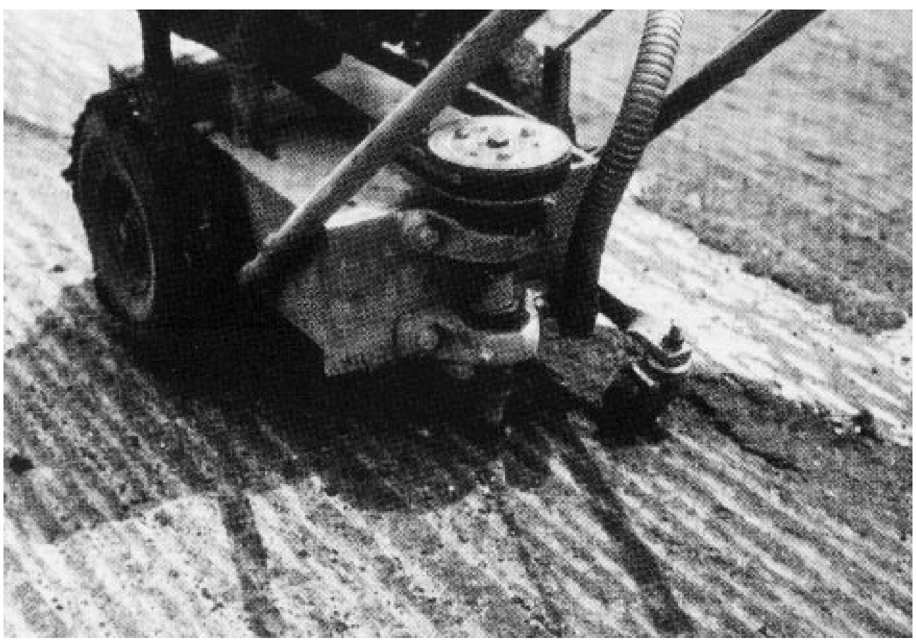

Photo 4. Vertical Spindle router

Sandblasting Equipment

The necessary sandblasting equipment includes an air compressor, air hose, and a 0.25-in.- (6-mm-) diam venturi-type nozzle. The compressor must be capable of delivering 150 cu ft/min (4.25 cu m/min) at 90 lb/sq in. (620 kPa) and be equipped with in-line traps to keep the air hoses and the sandblasted surface free of oil and water. This device must be capable of removing all sawed slurry, dirt, and old sealant that may be present in cracks that are being resealed. Ceramic and tungsten carbide nozzles are available for sandblasting, but the tungsten nozzles last longer. A guide that keeps the nozzle a constant height from the pavement surface promotes consistency to the sandblasting technique and reduces operator fatigue.

Safety must always be a primary concern. Sandblasting operators are required to follow OSHA guidelines. A helmet with a separate air source and air purification equipment reduces the possibility of inhalation of silica dust. Protective clothing may also be required.

Compressed Air Equipment

Compressed air can be employed for the final cleaning phase of the project. The air source must produce sufficient pressure and contain no oil that may foul the surface prior to sealing. Some compressors have in-line oil sources for the constant lubrication of air tools. These devices must be removed along with the oil-coated pressure hoses, and in-line oil and water traps must be installed to provide a clean air source for the airblasting operation.

Hot-Air Lance

A hot-air lance is sometimes employed to dry the surface of the pavement immediately prior to sealing (Photo 5). Strict safety precautions that must be employed to reduce operator hazard may include protective clothing as well as eye and ear protection. The operator must take special precaution not to overheat the pavement which may cause cracks and chalking of the concrete surface. Direct flame devices must not be used.

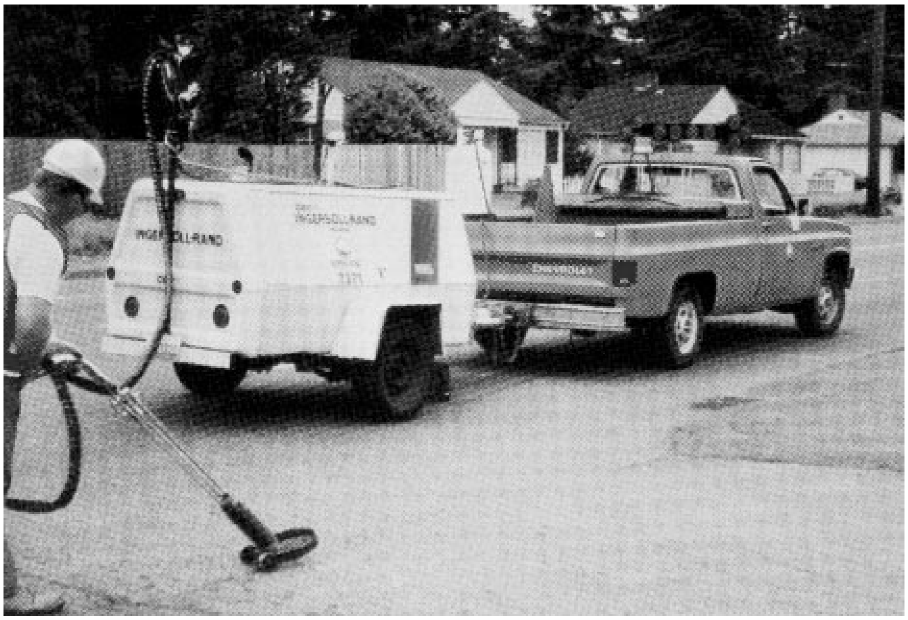

Photo 5. Hot-air lance

Waterblasting Equipment

Waterblasting is an excellent technique for cleaning joint faces and is sometimes employed as an alternative to sandblasting in areas with restrictions on sandblasting due to local air regulations or where the sand and debris might create additional problems. Waterblasting equipment should consist of a trailer-mounted water tank, pumps, high-pressure hoses, an auxiliary water supply, a wand with a safety cutoff if the operator should lose control, and a proper size nozzle for the crack width (Photo 6).

Photo 6. High-pressure water cleaning

Power Broom

A vacuum-type power broom should always be present to remove debris from the pavement surface and reduce the potential for FOD (Photo 7).

Photo 7. Power broom

Backer Rod Installation Equipment

Backer rod may be placed by hand and many contractors have constructed their own hand-held equipment for this operation. However, there are manufacturers of installation equipment. These devices place the rod at a consistent depth without undue stretching or tearing of the backer materials (Photo 8).

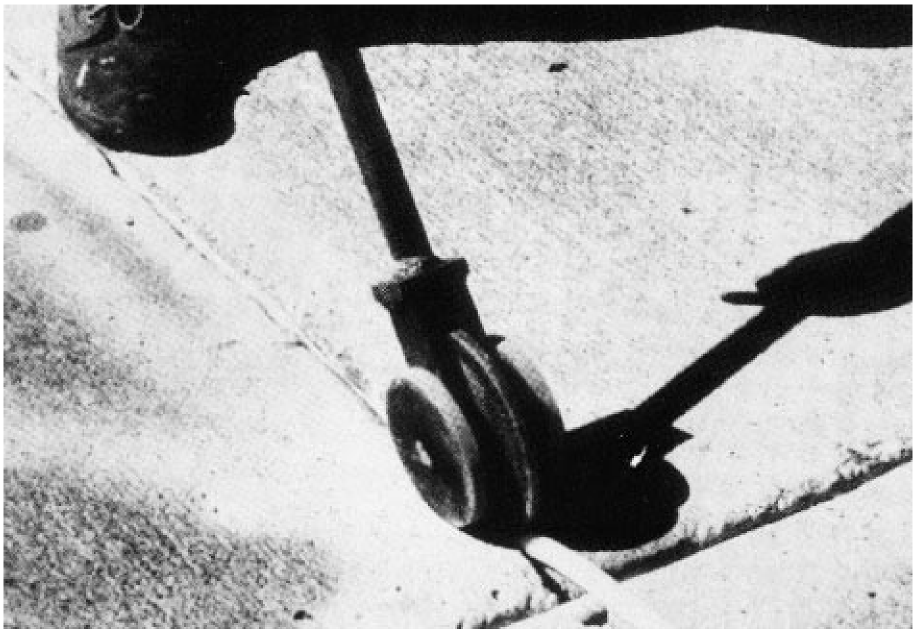

Photo 8. Installation of backer rod

Hot-Applied Sealant Equipment

There are two basic types of hot-applied sealant equipment: one for heating sealants that are solids or liquids at room temperature, and one for sealants that are liquids only. The former devices are much more prevalent. Both types must be capable of holding a sufficient amount of sealant and be able to heat the material to the proper application temperature (usually between 163°C (325°F) and 249°C (480°F)) without overheating.

The equipment necessary for application of room-temperature solid sealants must consist of a double-wall type kettle that is heated by a fluid between the walls of the chamber and a mechanical agitator to prevent localized overheating at the walls. Calibrated thermometers must be easily visible to allow constant monitoring of the sealant temperature to prevent the possibility of overheating. The sealant must be circulated through the delivery hose and back to the heating chamber when not being applied.

The equipment employed to apply sealants that are liquids at room temperature does not maintain the sealant reservoir at the application temperature. The sealant is heated just prior to application by pumping through transfer lines immersed in an oil bath.

Cold-Applied Sealant Equipment

The necessary equipment for application of cold-applied sealants depends on whether the sealant is a single-component or a two-component mix and whether the material is hand-mixed or machine-mixed. Two-component machine mixers consist of an extrusion pump, air compressor, and the associated hoses to dispense the components through separate nozzles and mixed in a 50:50 ratio with less than ±5 percent error just prior to discharge from the nozzle. Hand-mixing equipment for two-component sealants is generally a slow-speed electric drill with a paddle mixer or an air-powered mixer. Single-component sealant applicators are similar to those for two-component mixtures but do not require a mixing step before application to the pavement. Small hand-held caulking guns can also be employed for small jobs.

Crack Preparation

One essential element of the crack sealing operation is proper preparation of the crack and the crack face. If the prepared cracks are dirty or contain excess moisture, the sealant will not completely adhere to the surface and eventually will separate from the crack wall. The crack sealing operation must be scheduled such that the prepared cracks are sealed as soon as possible to prevent contamination before sealant application. If vegetation is growing in the cracks, a water-based herbicide must be used to kill the weeds. Oil-based herbicides can leave a residue that may prevent adhesion of the sealant to the crack face. The cracks must be routed or sawed out to the proper depth and width according to the shape factor designated by the manufacturer’s recommendations for the particular sealant being employed (Photos 9 and 10). After completion of the sawing operation, the crack face must be sandblasted to remove laitance, sawing debris, and other foreign material. Sandblasting must be conducted with a multiple-pass technique in which one side of the sawed crack face is abraded, followed by the other face

Photo 9. Hand sawing a crack

(Photo 11). The pavement surface directly adjacent to the sawed crack must also be blasted to remove any debris or material that may cause problems during crack sealing.

The importance of proper cleaning of the crack faces cannot be overemphasized. Surface dust, debris, and laitance remaining in the sawed crack can prevent adhesion of the crack sealant to the prepared face. The sandblasting operation must be followed by an initial cleaning with high-pressure air followed by high-pressure water to remove material remaining in the sawed

Photo 10. A freshly sawed crack

Photo 11. Sandblasting a joint face

cracks. This process must be repeated immediately prior to placing the sealant in the sawed reservoir if the sealant is not placed within a few hours of the cleaning. A power broom or hand broom must be used to remove sand and dust to prevent the sand and dust from re-entering the crack (References 7-9).

Crack Sealing Procedures

The crack sealing operation should only be conducted when pavement temperatures are above 50°F (10°C). Application temperatures for hot-applied crack sealants should constantly be monitored to ensure that they are in the correct range. Crack faces should be clean and free of moisture. If moisture is present, a hot-air lance or compressed air can be used to dry the crack face before sealing. The crack must be filled from the bottom up to prevent air from becoming trapped under the sealant and causing bubbling. The crack must also be filled from beginning to end in one smooth operation whenever practical (Photo 12).

Figure 12. Sealing a crack

Spall Repair

The recommended method for spall repair is the saw and patch method. The joint or crack sealant adjacent to the spall area must be removed. A boundary surrounding the spalled area is sawed using a concrete saw. For a joint spall, the minimum length of a 2-in. (5-cm) full depth sawcut is 12 in. (30 cm) for both the length and width of the rectangular spall repair boundaries. For corner spalls, the sawcuts should be no less than 12 in. (30 cm) from the joint corner and extend a minimum of 4 in. (10 cm) perpendicular to the joint. A third cut is then made between the two 4-in. (10-cm) cuts to form a pentagon with the joint corners and sawcuts comprising the five sides. A light jackhammer is then used to remove the concrete within the boundary to a depth of at least 2 in. (5 cm). If a dowel is exposed during the concrete removal, it must be replaced. Procedures for dowel replacement will not be covered here, but may be found in References 1, 6, and 9. After removing the concrete within the boundary, the underlying concrete should be checked for soundness. A joint filler is used to maintain the existing joint or crack. Under no circumstances should the spall repair bridge the joint. If PCC is to be used in the spall repair, a bonding agent must be used to ensure a good bond between the old concrete and the patching material. Curing procedures for PCC must be strictly followed to prevent shrinkage cracking. If proprietary concrete patching materials are to be used in the repair, be sure to follow the manufacturer’s recommendations for bonding agents, mixing, placement, and curing. After the spall area has been filled, the joint or crack must be sealed.

Before beginning a full-scale patching operation, a test area of spall repair must be conducted. This ensures familiarity with equipment and materials and any potential problems with techniques, etc., before beginning the full-scale repair operation. Additional information on spall repair is available in References 10-12. The reference section also includes all applicable ASTM test methods as well as references for information on concretes from the American Concrete Institute (ACI).

Spall Repair Materials

Specifications

The particular repair materials chosen for the repair operation must conform to the appropriate specifications (see the ASTM methods in the References). For Navy pavements, use of asphalt patching materials for temporary spall repair is allowed. The Army and Air Force do not allow the use of asphalt patching materials for spall repair. The concrete, curing compound (if used), sealant (see the section "Crack Sealants"), backer rod (see the section "Backer Materials"), and joint filler must meet ASTM specifications. Joint fillers can be asphalt-impregnated fiber-board, styrofoam sheeting, sponge rubber, or cork but must conform to ASTM D 1751 or D 1752. Recommended maximum aggregate size is 3/8 in. (1 cm). PCC Type I concrete is the required patching material unless other materials are approved by the base engineer. Type II concretes are generally not necessary for repair projects. Fast-setting concretes (Type III) can be employed when the repair area must be opened to traffic within 1 to 3 days after placement. Concretes are available that allow the repaired area to bear traffic within 1 hr. The PCC should have a range of from 0.5 in. (13 mm) to 2 in. (50 mm) of slump and meet a minimum compressive strength of 5,000 psi (35 MPa) at 28 days of age. On U.S. Navy facilities, the materials chosen must meet all of the specifications outlined in NFGS-02983 (Reference 10) and NFGS-02982 (Reference 3). For U.S. Army and Air Force facilities, refer to CEGS-02574 (Reference 11) and CEGS-02592 (Reference 5). For U.S. Air Force pavements repair, see Reference 6 also.

For filling small popouts, operators should use a sand cement mortar of one part cement to two parts sand. The water-to-cement ratio should not exceed 0.45 by weight.

Alternative Repair Materials

Spall repair materials can be classified into three broad categories: cementitious, polymeric, and bituminous. Only the cementitious or polymeric materials are approved for use on airfields. Bituminous materials must not be employed as a spall repair material on Army and Air Force airfields due to the potential for FOD. Typical concerns for selection of a spall repair material are cost, physical properties, curing time (how soon can the section be opened to traffic), material availability, familiarity with the product, etc. There are numerous products for concrete repair that address various aspects of the repair project such as high early-strengths, rapid set times, ease of workability, low shrinkage, and low permeability. However, since use of rapid-setting concretes and polymer concretes may require very different placement and curing procedures, personnel should be aware of what is required for the repair material before making a decision. Use of admixtures to PCC, rapid-setting, and polymer concretes must meet appropriate specifications (ASTM C 260 and C 494) and must be approved by base engineers prior to using these materials in any paving projects. If using fast-setting Type III polymer concretes, or admixtures, the manufacturer’s recommendations on the use and cleanup of these materials should be followed to avoid problems. Fast-setting (Type III) concretes require different procedures for mixing and placing than do polymer concretes. Mixing procedures for the polymer concretes vary depending on the material. Rapid-setting concrete mixes may harden much faster when temperatures are above 90°F (32°C). Retarding compounds can be added to the mixtures to slow the curing process at pavement temperatures above 90°F (32°C), or special mixtures premixed with retarders that extend the setup time are also available. Due to the high heat released upon curing of many of the polymer materials, only 2-in. (5-cm) or smaller lifts are suggested. Cleanup of rapid-setting materials must begin soon after placement to prevent these materials from ruining equipment. Guidelines for use in placement of polymer concretes are provided in ACI 548.1R.

Spall Repair Equipment

Much of the equipment necessary for spall repair has been previously described under “Crack Preparation.” However, additional equipment such as concrete saws, jackhammers, mixers, small spud vibrators, and hand tools may also be necessary.

Concrete Saws

A concrete saw is similar to a random crack saw but generally is less maneuverable and has a larger blade (Photo 13). Concrete saws are employed extensively for refacing joints for joint sealing projects but are often used for large patching operations or full-depth repair. Small blades of 6 to 10 in. (17 to 25 cm) should be used to minimize the size of the sawcuts for sawing out the spall area. Larger blades may be necessary for refacing joints or cracks. Small patches can be sawed with a random crack or a hand-held saw.

Photo 13. Sawing out the edges of a spalling area

Jackhammers

The jackhammer needed for large patching operations where full-depth repairs are needed may be a 30-lb (13.6-kg) model; for smaller jobs, a 10- to 15-lb (4.6- to 6.8-kg) model is sufficient (Photo 14). The jackhammer must be equipped with a chipping hammer and worked at an angle of between 45 and 90 degrees relative to the pavement surface. Special care must be taken not to damage the layer of concrete under the spall repair area or cause microcracking around the repair.

Photo 14. Using a jackhammer to remove damaged concrete

Mixers

Drum or mortar mixers are usually employed for most patching operations. Buckets may be used with a hand-held paddle-wheel mixer for smaller operations.

Hand Tools

Hand tools such as shovels, trowels, and screeds must be available.

Spall Repair Preparation

As with most concrete repairs, an essential element of the spall repair operation is the proper preparation of the spalled area. If the prepared spalls are dirty or contain excess moisture, the repair material or bonding agent may not completely adhere to the surface. The spall repair operation must be scheduled such that the prepared areas are filled as soon as possible to prevent contamination of the surface. The importance of proper cleaning of the repair area cannot be overemphasized. After completion of the sawing and removal of the concrete, the recess must be cleaned by airblasting and waterblasting to remove concrete chips, laitance, sawing debris, and other foreign material from the recess. The area must then be thoroughly swept, using a vacuum broom if available, to prevent debris from reentering the spall repair area.

Detailed schematics of spall repair for construction and keyed joints are presented in Figures 1-4. Figure 1 provides details for determining the boundary around the spall where the sawcuts should be located. Repair boundaries for corner spalls and joint spalls at both construction and keyed joints are shown. Closeup details for each of the types of spall repair located in various positions around a slab are given in Figures 2-4. Figure 5 shows details for joint sealant repair, and Figure6 gives details for repair of popouts.

To begin the saw and patch procedure, mark the boundaries of the area to make the sawcuts easier and decide which repair material(s) are to be employed in the patching effort. Remove the joint or crack sealant a few inches on either side of the spall. The sawcuts must be at least 2 in.

(5 cm) deep and 2 to 3 in. (5 to 8 cm) outside the boundary of the spall (See Figure 2 and Photo 13). For joint and crack spalls, the sawcuts should be straight and at right angles to each other with the cuts forming a rectangle with the joint or crack as one side. For corner spalls, the initial cuts should be at least 4 in. (10 cm) long and perpendicular to the joint with the final cut joining the initial cuts to form a pentagon at the slab corner (Figure 2). The jackhammer may then be used to remove the concrete to a depth of at least 2 in. (5 cm) within the cut area by starting in the center of the spall and working towards the cuts (Photo 14). If both sides of the joint or crack are spalled, the spall on each side of the joint must be repaired while maintaining the joint or crack. An example is shown in Photo 15. Joint filler is placed in the expansion joint, and the spalls on each side of the joint are repaired independently. See References 7-9 and 12 for additional details on joint sealant removal and repair.

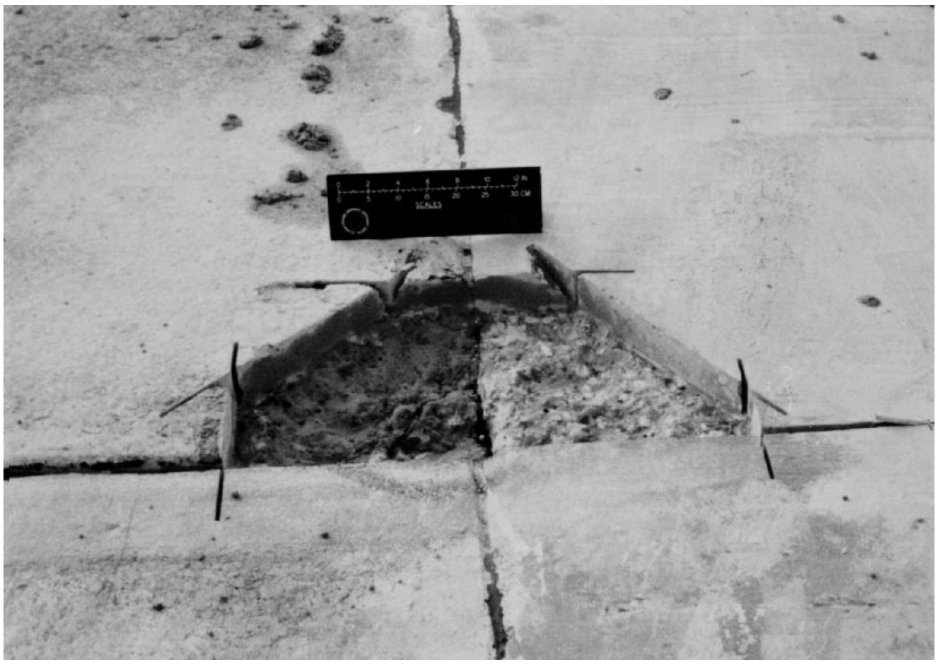

Photo 15. A spalled area on both sides of an expansion joint ready for installation of joint filler

After the concrete in the area has been removed, it must be tested for soundness to ensure that there are no cracks in the underlying concrete or loose material present. This can be easily accomplished with a steel rod, a short length of chain, or a ball peen hammer. A dampened ring from the steel indicates a crack or loose material beneath the sounding device. If unsound concrete is located, it must be removed to a depth of at least 1/2 in. (13 mm) into sound concrete. A thorough cleaning must be conducted by compressed air and high-pressure water of the repair area to remove debris. A power broom, vacuum sweeper, or at least a thorough hand broom sweeping of the area must be conducted to prevent debris from re-entering the repair zone.

Spall Repair Procedures

The repair process begins after the final cleaning of the area. The area must be dry and free of dust, oil, dirt, etc. A good repair begins with a clean surface. Since the volume of most spall repairs is usually small, most mixing must be done in a small drum or mortar mixer. Some repair materials come premixed and others allow the mix to be extended by adding aggregate (maximum recommended size is 3/8in. or 1 cm). The material must be consolidated by vibration or tamping and the surface worked to match the surrounding finish as closely as possible.

If the spalled area is adjacent to an expansion joint or a crack, a joint filler must be employed to prevent the repair material from fouling the joint (Photo 16) and to retain the joint shape. If the spall is next to a crack, the crack must be treated as an expansion joint. Spall repairs must not bridge cracks or expansion joints. The crack must be formed up just as an expansion joint. The joint filler should be the

Photo 16. Application of bonding agent to the concrete surface. Note the joint filler bordering the repair area

same width as the existing joint and should be long enough to cover the spall area and deep enough to cover the full depth of the spall.

Bonding agents are utilized to improve the bond between the patch and the patch repair materials. A bonding agent must be used when using PCC as the repair material. If using a rapid-setting or polymer concrete, consult the manufacturer's recommendations on the use of bonding agents. For PCC repairs, the bonding grout used is a mixture of one part portland cement to one part sand with a water-to-cement ratio less than 0.62 (Reference 10). The bonding agent must be brushed into cracks and crevices to ensure good contact with the repair surface (Photo 16). Many repair materials are proprietary and may also require a proprietary bonding agent. When employing these types of material in the repair, the manufacturer's recommendations must be followed closely. The entire surface of the repair area must be coated or sprayed with the bonding agent, and the repair material must be placed when the bonding agent has reached a tacky consistency. If the bonding agent is dripping through small openings where the joint filler meets the bottom of the spall recess, a small bead of caulk may be placed to prevent the dripping.

The mixing and placing of spall repair materials often varies considerably due to the widely different materials that can be used. It is good practice to place the repair material at pavement temperatures above 55°F (13°C) and below 90°F (32°C). The correct amount of clean, fresh water must be added and thoroughly mixed. Hand mixing almost always requires more time than drum or mortar mixers. When hand mixing, there is also a tendency to add more water than required to ease the mixing effort. Manufacturer's recommendations for mixing and curing of materials must always be strictly followed to ensure a quality patching job. For more details on placing concrete in hot and cold weather, refer to ACI 305R and ACI 306R. Repair materials must not be placed at temperatures less than 40°F (4°C) and only with special insulation and longer cure times for temperatures less than 55°F (13°C). In summer, it is best to place repair materials in the morning when pavement temperatures are lower. In winter, afternoons are best.

After placement, the repair material must be consolidated to remove trapped air. Cementitious and polymer concrete materials require some type of consolidation, either by tamping or by vibration (Photo 17). Vibrators with a small (less than 1 in. or 25 mm) head or vibratory screeds are recommended for small repairs. Grate tampers must not be used. After consolidation, the repair material must be finished to match that of the surrounding pavement (Photo 18). A completed patch is shown in Photo 19 where the spall repair was conducted on both sides of the expansion joint. Note the joint filler separating the spall repair.

Photo 17. Consolidation of the repair material by vibration

Curing of the material is very important, especially for partial depth repairs where the surface- area-to-volume ratio of the repair area is larger than a full-depth repair. Rapid water loss from the surface due to high temperatures, low humidity, and/or windy conditions can result in severe shrinkage cracking on the surface. Curing compounds are recommended (see ASTM C 309). For PCC patches, polyethylene sheeting, water-soaked burlap, cotton mats, or rugs placed over the

Photo 18. Finishing the patch surface

Photo 19. A completed spall repair that bridges an expansion joint

repair surface can be used to prevent excess water loss from evaporation (ASTM C 171) during the cure for at least 24 hr. The fresh PCC should be covered or coated as soon as possible after finishing the surface and should be left on a minimum of 24 hr, preferably longer. Guidelines for curing are given in ACI 308. Special curing procedures for rapid-setting concretes must be followed to prevent excessive shrinkage cracking. These materials harden rapidly and severe plastic shrinkage cracking may develop on the surface if the materials dry too fast. Manufacturer's recommendations for curing of proprietary concretes must be followed.

After the patch has cured, the final repair step is to replace the sealant to maintain the existing joint or crack. Joint or crack resealing should not begin until the concrete curing process is complete. The joint sealing operation is analogous to crack sealing. The joint or crack adjacent to the spall is sawed out to the same width as the existing joint or crack using a concrete saw, router, or hand saw. The joint filler must be completely removed either by hand or by sawing. Joint preparation should conform to the specifications outlined in Figure 6. The sides of the sawcuts are then sandblasted, airblasted with compressed air, and washed with high-pressure water to prepare a good surface for sealant adhesion. The area surrounding the repair should be swept with a vacuum broom to remove debris, etc. After cleaning the area, backer rod is installed in the joint or crack recess. For U.S. Army and Air Force facilities, the joint sealant employed must conform to the Federal specifications for the particular location in which the sealant is being replaced. For pavements on naval facilities, the joint sealant must conform to NFGS-02582; however, silicone sealants may be used in lieu of materials meeting Federal specifications

(References 3 and 4). Placement of the sealant is similar to that of crack sealants in that the sealant should be placed from the bottom up and in a smooth stroke from the beginning to the end of the joint or crack, if practical. For details on sealing of joints, refer to the section on crack sealing as this is analogous to sealing joints. In addition, procedures for sealing joints are given in References 5-8.

After the repair is complete, all equipment should be cleaned, lubricated if necessary, and properly stored until needed for the next repair operation.

References

1. “Concrete Pavement Repair Manual,” Department of the Navy, MIL-HDBK-1102/7.2.

2. “Procedures for U.S. Army and U.S. Air Force Airfield Pavement Condition Surveys,” Departments of the Army and Air Force, TM 5-826-6/AFM93-5, Washington, DC, 1989.

3. “Resealing of Joints in Rigid Pavement,” Department of the Navy, Naval Facilities Engineering Command, Guide Specification NFGS-02982, December 1995.

4. “Silicone Joint Sealants for Pavements,” Engineering Technical Letter ETL 94-9, Air Force Civil Engineering Support Agency, Tyndall Air Force Base, FL, December 1994.

5. “Field Molded Sealants for Sealing Joints in Rigid Pavements,” Department of the Army, U.S. Army Corps of Engineers, Guide Specification for Military Construction CEGS-02592, April 1991.

6. “Repair of Rigid Pavements Using Epoxy-Resin Grouts, Mortars, and Concrete,” Departments of the Army and Air Force, TM-5-822-9, Chapter 10.

7. “Materials and Procedures for the Repair of Joint Seals in Concrete Pavements,” Evans, L.D., and Romine, A.R., SHRP-H-349, 1993, Strategic Highway Research Program, Transportation Research Board, Washington, DC.

8. “Concrete Joint and Crack Repair,” Air Force Engineering and Services Center, Tyndall Air Force Base, FL.

9. “Concrete Repair Field Manual,” Air Force Engineering and Services Center, Tyndall Air Force Base, FL.

10. Federal Specification SS-S-1401C, 1984, “Sealant, Joint, Non-Jet-Fuel-Resistant, Hot-Applied, for Portland Cement and Asphalt Concrete Pavements”; Federal Specification SS-S-1614A, 1984, “Sealants, Joint, Jet-Fuel-Resistant, Hot-Applied, for Portland Cement and Tar Concrete Pavements”; Federal Specification SS-S-200E, 1984, “Sealants, Joint, Two-Component, Jet-Blast-Resistant, Cold-Applied, for Portland Cement Concrete Pavement,” General Services Administration, Washington, DC.

11. “Patching of Rigid Pavement Partial Depth,” Department of the Navy, Naval Facilities Engineering Command, Guide Specification NFGS-02983, December 1995.

12. “Patching of Rigid Pavements,” Department of the Army, U.S. Army Corps of Engineers, Guide Specification for Military Construction CEGS-02574, February 1989.

13. “Materials and Procedures for Rapid Repair of Partial-Depth Spalls in Concrete Pavements,” Evans, L.D. et al., SHRP-H-349, 1993, Strategic Highway Research Program, Transportation Research Board, Washington, DC.

American Society for Testing and Materials (ASTM)

Listed below are the applicable ASTM specifications for sealants, joint fillers, patching materials, etc.

Joint and Crack Repair

ASTM C 603	(1990) Extrusion Rate and Application Life of Elastomeric Sealants
ASTM C 639	(1990) Rheological (Flow) Properties of Elastomeric Sealants
ASTM C 661	(1993) Indentation Hardness of Elastomeric-Type Sealants by Means of a Durometer
ASTM C 679	(1987; R 1992) Tack-Free Time of Elastomeric Sealants
ASTM C 719	(1993) Adhesion and Cohesion of Elastomeric Joint Sealants Under Cyclic Movement
ASTM C 792	(1993) Effects of Heat Aging on Weight Loss, Cracking, and Chalking of Elastomeric Joint Sealants

ASTM C 793	(1991) Effects of Accelerated Weathering on Elastomeric Joint Sealants
ASTM D 412	(1992) Vulcanized Rubber and Thermoplastic Rubbers and Thermoplastic Elastomers -Tension
ASTM D 1751	(1983; R 1991) Preformed Expansion Joint Filler for Concrete Paving and Structural Construction (Nonextruding and Resilient Bituminous Types)
ASTM D 1752	(1984; R 1992) Preformed Sponge Rubber and Cork Expansion Joint Fillers for Concrete Paving and Structural Construction
ASTM D 2628	(1991) Preformed Polychloroprene Elastomeric Joint Sealers for Concrete Pavements
ASTM D 2835	(1989; R 1993) Lubricant for Installation of Preformed Compression Seals on Concrete Pavements

Spall Repair

ASTM C 31	(1991) Making and Curing Concrete Test Specimens in the Field
ASTM C 33	(1993) Concrete Aggregates
ASTM C 39	(1993; Rev. A) Compressive Strength of Cylindrical Concrete Specimens

ASTM C 94	(1994) Ready-Mixed Concrete
ASTM C 131	(1989) Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine
ASTM C 136	(1993) Sieve Analysis of Fine and Coarse Aggregate
ASTM C 143	(1990; Rev. A) Slump of Hydraulic Cement Concrete
ASTM C 150	(1994) Portland Cement
ASTM C 171	(1992) Sheet Materials for Curing Concrete
ASTM C 173	(1993) Air Content of Freshly Mixed Concrete by the Volumetric Method
ASTM C 231	(1991; Rev. B) Air Content of Freshly Mixed Concrete by the Pressure Method
ASTM C 260	(1986) Air-Entraining Admixtures for Concrete
ASTM C 309	(1993) Liquid-Membrane-Forming Compounds for Curing Concrete
ASTM C 494	(1992) Chemical Admixtures for Concrete

American Concrete Institute (ACI)

Listed below are the applicable ACI publications pertaining to spall repair that detail good practices for concrete repair work.

ACI 305R-88	Hot-Weather Concreting
ACI 306R-88	Cold-Weather Concreting
ACI 308-92	Standard Practice for Curing Concrete
ACI 548.1R	Guide for the Use of Polymers in Concrete